

Final Technical Report
Electron Dynamics in the Magnetotail
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Brief Proposal Summary

The goal of this research has been to study the effects of electrons on magnetotail dynamics and current sheet structure. The approach is to follow ion trajectories in a global model of the magnetotail, use a Boltzmann approximation to include electrons, and then to update the field model according to the currents that are generated by the cross-tail electric field and/or induced fields. Parallel (and perpendicular) electric fields that form are included through the Boltzmann relation. Transverse electron currents are to be included through adiabatic drift equations.

Original Work Plan

The first goal was to include electrons via the Boltzmann relation into a simulation code that already includes ions and update the fields according to the currents that form in the midtail plasma neutral sheet. In the mid-magnetotail where there is a field reversal, the magnetic field is at it's weakest and that is where ion motion can be non-adiabatic. At those locations, ions can be accelerated directly across the magnetotail and large ion currents can develop, which in turn modify the global field configuration. After inclusion of electrons through the Boltzmann relation, a number of runs were to be carried out with different values for the electron energy (parallel and perpendicular). After carrying out these runs and analyzing the results, our next goal was to include transverse electron motion and determine the contribution of electron current (compared to the ion current) in the magnetotail cross-field current sheet.

Progress

The starting point for this research is an existing code called Large Scale Kinetic-Self Consistent (LSK-SC). This code follows ions in a model magnetic field (using the Zwingman analytical field model) of the Earth's magnetotail and updates the magnetic field using the Biot-Savart law according to the ion currents calculated from the particles. The first main task we completed was to incorporate the Boltzmann relation into the LSK-SC code. The Boltzmann density relation for electrons was included into the code using:

$$n = n_0 e^{(q\phi - \mu B) / kT}$$

where n is the density at any location, n_0 is the density at the equator, q is the charge, ϕ is the electrostatic potential, μ is the adiabatic invariant, B is the magnetic field, k is Boltzmann's constant, and T is the electron temperature. The $q\phi$ term is due to charge separation and the μB term is due to the mirror force. Quasi-neutrality is assumed for the density and at any position in the magnetotail the ion density is calculated from the LSK-SC code, which is taken as being equal to the electron density. Since all of the other parameters are known or are specified in the above

equation, the electrostatic potential can be calculated at different locations in the magnetotail. The LSK-SC code was successfully modified to include the Boltzmann's relation and these initial results were reported at the Chapman Conference on Magnetospheric Current Systems in Hawaii in January 1999.

With the newly modified LSK-SC code, we have carried out a number of simulation runs for different electron temperature profiles; the electron temperature is the only free parameter in the above equation (apart from ϕ which is what is being solved for). We started by taking typically observed electron temperatures in the plasma sheet with an isotropic temperature profile (i.e., parallel temperature T_{\parallel} , equal to the perpendicular temperature T_{\perp}) and then considered the anisotropic case ($T_{\parallel} \neq T_{\perp}$). The first simulation runs carried out with the new code were such that the magnetic field was fixed (rather than using the ion currents to update the fields). The reason for doing this was to first see how the inclusion of electrons, and in particular the inclusion of a parallel electric field (due to ϕ), affects ion motion and current sheet structure. This made it easier to understand the physics for the dynamic case.

For the static runs we found that for electron temperatures of 500 eV, with a temperature anisotropy of $T_{\parallel} = 5T_{\perp}$, a parallel electric field forms in the deep tail neutral sheet acceleration region (near the X-line). This parallel electric field tends to pull ions out of the central plasma sheet to balance the density decrease that occurs from the central plasma sheet out towards the lobe. This effect makes the current sheet thicker. Closer to the Earth the mirror force counteracts this effect until equilibrium is reached. These results were reported at the Spring AGU meeting in Boston in June 1999 and at the IAGA meeting in England in July 1999. More runs varying the electron temperature value and the ratio of T_{\parallel}/T_{\perp} have been carried out. So far we have seen that the formation of parallel electric fields is very sensitive to the temperature anisotropy, and to a lesser degree on the absolute value of the temperature (ranging between 200 eV and 700 eV). These findings were reported at the Fall AGU meeting in San Francisco in December 1999 and at the Fifth International Conference on Substorms in St. Petersburg, Russia in May 2000 that also included a conference proceeding in which the results were published.

The next step was to move beyond the static cases into the dynamic regime by carrying out runs in which the global magnetic field was updated according to the ion currents (also including the Boltzmann electrons). Thus a major goal of running the LSK-SC code dynamically with the contribution of electrons included has now been realized. As expected, the ratio of T_{\parallel}/T_{\perp} had a strong effect on the results. An important finding is that the X-line location on average is further from the Earth. Also, the period of oscillation of the X-line location (compared to the case with ions only) is different due to the presence of the Boltzmann electric fields, which tends to pull ions out of the current sheet and affect the loss rates. The thickness of the current sheet is strongly dependent on the electron energies used in these runs. Also, the Boltzmann electric fields that form in the parallel and perpendicular directions affect the ion precipitation profile and the particle loss from the system through the flanks and down the magnetotail. These results were reported at the First SRAMP Conference in Sapporo, Japan in October 2000 and the 2000 Fall AGU Meeting in San Francisco. This work has also been published in *Advances of Space Research*.

The most recent effort has been to include electron transverse motion and their direct contributions to the cross-tail current. This is done by including a transverse drift velocity for the electrons based

on the guiding center equations (rather than using just the Boltzmann relation). The guiding center terms include $\mathbf{E} \times \mathbf{B}$ convection and the diamagnetic drift. From each of these terms, depending on the electron energy, density, and location of the electrons in the magnetotail, a cross-field velocity can be determined (v_{\perp}) and thus an electron current can be calculated ($-nqv_{\perp}$). Results show that in most locations in the magnetotail current sheet the contribution of electron current to the total current is small, however, in the vicinity of an O or X-line the electron current can be large and in fact dominate the total current.

Publications

Peroomian, V., M. Ashour-Abdalla, L.M. Zelenyi, and A.A. Petrukovich, Intrinsic self-adjustment and variability of the magnetotail. *Proc. 5th International Conference on Substorms, ESA SP-443*, 121, 2000.

Peroomian, V., D. Schriver, L.M. Zelenyi, Imprints of small-scale nonadiabatic particle dynamics on large-scale properties of dynamical magnetotail equilibria, *Adv. Space Res.*, *in press*, 2002.

Presentations and Abstracts

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Schrive, D., M. Ashour-Abdalla, V. Peroomian, and L. Zelenyi, The role of electron currents in magnetotail dynamics. *American Geophysical Spring Meeting*, Boston, June, 1999 (*EOS*, 80, S279).

Ashour-Abdalla, M., V. Peroomian, L.M. Zelenyi, and D. Schriver, Modeling field aligned potentials produced by non-adiabatic ion motion in the plasma sheet, *The 22nd General Assembly of the International Union of Geodesy and Geophysics*, Birmingham, England, July 1999.

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